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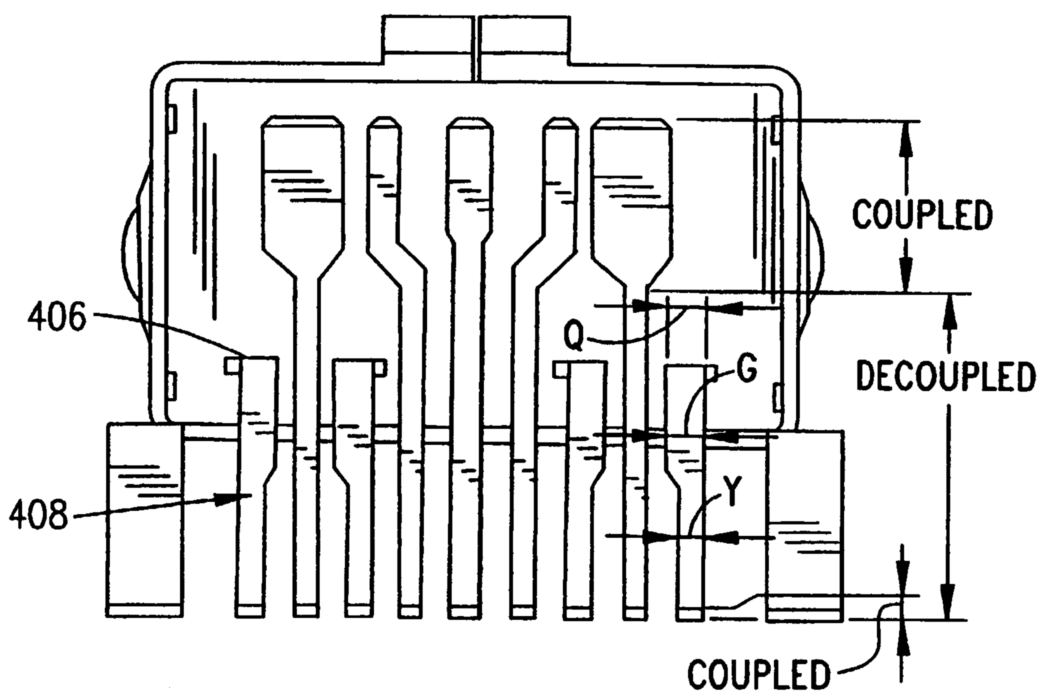

(57) **Abstract:** A connector with controlled impedance includes at least one set of differential signal terminals with an associated ground terminal. The ground terminal has a symmetric configuration, while the two differential signal terminals have asymmetric configurations. The asymmetric configurations permit capacitive coupling to occur primarily between the two differential signals in an area of the connector where the inductance of the connector would be high. The two differential signal terminals flank the ground

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IMPEDANCE-TUNED CONNECTOR

Background of the Invention

The present invention relates generally to connectors, and more particularly to connectors having improved impedance characteristics and which are used in connecting signal cables to printed circuit boards.

Many electronic devices rely upon transmission lines to transmit signals between related devices or between peripheral devices and circuit boards of a computer. These transmission lines incorporate signal cables that are capable of high-speed data transmissions.

These signal cables may use what are known as one or more twisted pairs of wires that are twisted together along the length of the cable, with each such twisted pair being encircled by an associated grounding shield. These twisted pairs typically receive complimentary signal voltages, i.e., one wire of the pair may see a +1.0 volt signal, while the other wire of the pair may see a -1.0 volt signal. Thus, these wires may be called "differential" pairs, a term that refers to the different signals they carry. As signal cables are routed on a path to an electronic device, they may pass by or near other electronic devices that emit their own electric field. These devices have the potential to create electromagnetic interference to transmission lines such as the aforementioned signal cables. However, this twisted pair construction minimizes or diminishes any induced electrical fields and thereby eliminates electromagnetic interference.

In order to maintain electrical performance integrity from such a transmission line, or cable, to the circuitry of an associated electronic device, it is desirable to obtain a substantially constant impedance throughout the entire transmission path, i.e., through the cable, its connectors and onto the circuit or to avoid large discontinuities in the impedance of the transmission path. The difficulty of controlling the impedance of a connector at a connector mating face is well known because the impedance of a conventional connector typically changes through the connector and across the interface of the two mating connector components. Although it is relatively easy to maintain a desired impedance through an electrical transmission line, such as a cable, by maintaining a specific geometry or physical arrangement of the signal conductors and the grounding shield, an impedance change is usually encountered in the area where the connector that the cable engages, meets a printed circuit board It is therefore desirable to maintain a desired impedance throughout the connector and its connection to the cable.

The present invention is therefore directed to a connector structure that provides a high level of performance and which maintains the electrical characteristics of the transmission path through the connector to the circuit board.

Summary of the Invention

Accordingly, it is a general object of the present invention to provide an improved connector for high-speed data transmission connections in which the impedance discontinuity through the connector is minimized so as to better attempt to match the impedance of the transmission line.

Another object of the present invention is to provide an improved connector for effecting a high-performance connection between a circuit board and an opposing connector terminated to a transmission line, wherein the transmission line includes at least one pair of differential signal wires and an associated ground and the opposing connector includes at least two signal and one ground terminal, the connector having a pair of signal terminals disposed therein and a ground terminal associated therewith, the signal and ground terminals of the connector being arranged in a manner so as to reduce impedance discontinuities from occurring when the connector is mated to the opposing connector.

It is a further object of the present invention to provide such a connector wherein, by varying the size of the ground terminal and its location relative to its two associated signal wires, the impedance of the connector may be "tuned" to obtain a preselected impedance through the connector.

Yet another object of the present invention is to provide a connector for connecting cables, such as those of the IEEE 1394 type, to a circuit board of an electronic device, wherein the connector has a number of discrete, differential signal wires and associated grounds equal in number to those contained in the cables, the ground terminals of the connector being configured in size and location with respect to the signal terminals of the connector in order to minimize the drop in impedance through the connector.

It is yet a further object of the present invention to provide a connector for providing a connection between a circuit board and a connector associated with a signal cable, wherein the connector includes a pair of differential signal terminals and a ground terminal associated with the pair of signal terminals, the ground terminal being sized to control the impedance through the connector, and the ground terminal of the connector being spaced apart from the pair of

signal terminals throughout the body portion of the connector and including the contact and body portions of the terminals in order to establish and maintain a desired electrical relationship among the three terminals.

A still other object of the present invention is to provide an improved performance connector for mating to an opposing connector, the connector having a housing, a ground terminal positioned within the connector housing and spaced apart from two associated signal terminals, the ground terminal having a body portion that is larger than corresponding body portions of the two signal terminals, the ground terminal and two signal terminals being arranged in and maintained in a triangular orientation within both of the contact and body portions of the connector in order to reduce the level of impedance variations that occur through the connector when mated to an opposing cable connector.

In order to obtain the aforementioned objects, one principal aspect of the invention that is exemplified by one embodiment thereof includes a connector for a circuit board having a housing that supports for each twisted pair of wires in the mating signal cable, three conductive terminals in a unique pattern of a triplet, with two of the terminals carrying differential signals, and the remaining terminal being a ground terminal that serves as a ground plane or ground return to the differential pair of signal wires. The arrangement of the two differential signal terminals and their associated ground terminal within the board connector permits the impedance of the connector to be more effectively controlled from the mating area of the cable connector, through the body portion of the connector down and to tail portions of the connector terminals that are attached to the circuit board.

In this manner, each such triplet includes a pair of signal terminals that are aligned together in side-by-side order, and which are also spaced apart a predetermined distance from each other. The ground terminal for each differential pair of signal terminal is spaced apart from the two signal terminals so that two rows of terminals are presented in the mating area of the connector. The ground terminal has a contact portion that is spaced apart from like contact portions of the signal terminals, while the body portion of the ground terminal will also be spaced apart from the corresponding body portions of the signal terminals. In this extent, the ground terminal is also spaced apart from the two signal terminals in the vertical plane in which the terminal body portions extend in order to at least partially decouple the ground terminal from the differential signal terminals to provide a corrective increase in the impedance of the region of mating.

The width of the ground terminal and its spacing from the signal terminals may be chosen so as to obtain certain electrical characteristics, such as capacitance, inductance and the like, all of which will affect the impedance of the connector. The width of the ground terminal is increased in the mating area along the contact portions of the terminals, as well as in part of the transition, or body portions, that occur between the contact and tail portions of the terminals. The body portions of the ground terminals are spaced apart from and lie in a different plane than the body portions of the signal terminal body portions and, as such, the increased width of the ground terminals in their body portions will not adversely affect the side-by-side spacing of the terminal tail portions.

By this impedance regulating terminal structure, a greater opportunity is provided to reduce the impedance discontinuity which occurs in a connector without altering the mating positions or the pitch of the differential signal terminals. Hence, this aspect of the present invention may be aptly characterized as providing a "tunable" terminal arrangement for each differential signal wire pair and associated ground wire arrangement found either in a cable or in other circuits. The width of the ground terminals reduces from a first width down to a second width within the body portion of the ground terminals. The body portions of the ground terminals are spaced apart from a pair of associated differential signal terminals, and the width of these differential signal terminals reduces from a first width to a second width along the body portions thereof. The ground terminals preferably have a symmetrical shape and are aligned between the differential signal terminal body portions. The body portions of the signal terminals are asymmetrical along the extent, but they are arranged together in a symmetrical fashion so that they flank the ground terminal, when the connector is viewed from the rear and such that the ground terminal is elevated out of plane from the differential signal terminal pair.

In still another principal aspect of the present invention, the connector has its ground and signal terminals arranged in a triangular orientation to maintain the predetermined spatial relationships that occur among these three terminals in the mating area of the board connector. The use of asymmetrical signal terminals results in the differential signal terminals coupling primarily with each other in a region that is disposed beneath the location where the ground terminal width decreases. The larger width of the signal terminals along their body portion permits the ground terminal in the same area, i.e., along the body portions, to be reduced in width in the area closest to the differential signal terminal body portion. In this manner, coupling occurs between the ground and signal terminals in their contact portions and along their

body portions until the ground terminal reduces in width. At this point, the signal terminals become further "decoupled" from the ground terminal and primarily must then couple with each other in order to maintain the electrical relationship of the three terminals which yields the correct overall impedance. All three terminals eventually recouple in the tail portions of the ground and signal terminals where the ground terminal tail portion lies between the two associated signal terminal tail portions.

These and other objects, features and advantages of the present invention will be clearly understood through a consideration of the following detailed description.

Brief Description of the Drawings

In the course of the following detailed description, reference will be made to the accompanying drawings wherein like reference numerals identify like parts and in which:

FIG. 1 is a perspective view of a terminal arrangement known to control the impedance of a board connector;

FIG. 2 is a rear elevational view of the terminal arrangement of the board connector of FIG. 1;

FIG. 3 is a perspective view of one embodiment of a terminal and shield arrangement constructed in accordance with the principles of the present invention and intended for use in board connectors;

FIG. 4 is a rear elevational view of the terminal and shield arrangement of FIG. 3;

FIG. 5 is a top plan view of the terminal and shield arrangement of FIG. 3;

FIG. 6 is a perspective view of a connector constructed in accordance with the principles of the present invention, with a rear body portion thereof illustrated in phantom for clarity;

FIG. 7 is a perspective view of a first terminal housing element that supports a first set of terminals of the connector, which set includes the ground terminals of the connector;

FIG. 8 is a front elevational view of the terminal housing element of FIG. 7;

FIG. 9 is a perspective view of a second terminal housing element that supports a second set of terminals, including differential signal terminals of the connector and which is engageable with the first terminal housing element of FIG. 9;

FIG. 10 is a front elevational view of the second terminal housing element of FIG. 9;

FIG. 11 is a perspective view of a connector subassembly in which the first and second terminal housing elements are engaged together with the terminals thereof being formed into their final position;

FIG. 12 is a front elevational view of the connector subassembly of FIG. 12;

FIG. 13 is a perspective view of the connector subassembly of FIG 11, with a first conductive shield applied to a portion thereof;

FIG. 14 is a rear perspective view of the connector of FIG. 14, after a body portion is molded over a a portion of the connector interior shield and the terminal modules thereof;

FIG. 15 is a sectional view of the connector of FIG. 14, taken along lines 15-15 thereof;

FIG. 16A is a sectional view taken through an electronic device, illustrating an "internal" application of the connectors of the present invention;

FIG. 16B is another sectional view taken through an electronic device, illustrating an "external' application of the connectors of the present invention;

FIG. 17 is a diagram illustrating the typical impedance discontinuity exhibited in a cable to board connector and the impedance discontinuity exhibited in a system using connectors of the present invention;

FIG. 18 is a diagram of a cable-board connector assembly with the various regions thereof identified relative to the diagram of FIG. 17;

FIG. 19 is a perspective view of an alternate terminal structure used in connectors of the present invention; and,

FIG. 20 is a rear plan view of the terminal structure of FIG. 19, with the terminals removed from their terminal modules for clarity and the shield shown in place surrounding the terminals.

Detailed Description of the Preferred Embodiments

The present invention is directed to an improved connector particularly useful in enhancing the performance of high-speed cables, particularly in input-output ("I/O") applications as well as other type of applications, and the present invention attempts to impose a measure of mechanical and electrical uniformity on the termination area of the connector to facilitate its performance, both alone and when combined with an opposing connector.

Many peripheral devices associated with an electronic device, such as a video camera or camcorder, transmit digital and other signals at various frequencies. Other devices associated

with a computer, such as the CPU portion thereof, operate at high speeds for data transmission. High speed cables are used to connect these devices to the CPU and may also be used in some applications to connect two or more CPUs together. A particular cable may be sufficiently constructed to convey these high speed signals and typically will include differential pairs of signal wires, either as twisted pairs or individual pairs of wires.

One consideration in high speed data transmissions is signal degradation. This involves crosstalk and signal reflection which is affected by the impedance of the cable and connector. Crosstalk and signal reflection in a cable may be easily controlled easy enough in a cable by shielding and the use of differential pairs of signal wires, but these aspects are harder to control in a connector by virtue of the various and diverse materials used in the connector, among other considerations. The physical size of the connector in high speed applications limits the extent to which the connector and terminal structure may be modified to obtain a particular electrical performance.

Impedance mismatches in a transmission path can cause signal reflection, which often leads to signal losses, cancellation, etc. Accordingly, it is desirable to keep the impedance consistent over the signal path in order to maintain the integrity of the transmitted signals. The connector to which the cable is terminated and which supplies a means of conveying the transmitted signals to circuitry on the printed circuit board of the device is usually not very well controlled insofar as impedance is concerned and it may vary greatly from that of the cable. A mismatch in impedances between these two elements may result in transmission errors, limited bandwidth and the like.

FIG. 17 illustrates the impedance discontinuity that occurs through a conventional plug and receptacle connector assembly used for signal cables. The impedance through the signal cable approaches a constant, or baseline value, as shown to the right of FIG. 17 at 51. This deviation from the baseline is shown by the solid, bold line at 50. The cable impedance substantially matches the impedance of the circuit board at 52 shown to the left of FIG. 11 and to the left of the "PCB Termination" axis. That vertical axis "M" represents the point of termination between the socket, or receptacle, connector and the printed circuit board, while the vertical axis "N" represents the interface that occurs between the two mating plug and socket connectors, and the vertical axis "P" represents the point where the plug connector is terminated to the cable.

The curve 50 of FIG. 17 represents the typical impedance "discontinuity" achieved with conventional connectors and indicates three peaks and valleys that occur, with each such peak or valley having respective distances (or values) $\mathbf{H_1}$, $\mathbf{H_2}$ and $\mathbf{H_3}$ from the baseline as shown. These distances are measured in ohms with the base of the vertical axis that intersects with the horizontal "Distance" axis having a zero ("0") ohm value. In these conventional connector assemblies, the high impedance as represented by $\mathbf{H_1}$, will typically increase to about 150 ohms, whereas the low impedance as represented by $\mathbf{H_2}$ will typically decrease to about 60 ohms. This wide discontinuity between $\mathbf{H_1}$ and $\mathbf{H_2}$ of about 90 ohms affects the electrical performance of the connectors with respect to the printed circuit board and the cable.

The present invention pertains to a board connector that is particularly useful in I/O (" input-output") applications, and which has an improved structure that permits the impedance of the connector to be set so that it emulates the cable to which it is mated and reduces the aforementioned discontinuity. In effect, connectors of the present invention may be "tuned" through their design to improve the electrical performance of the connector.

FIG. 16A illustrates an exemplary "internal" environment in which the present invention finds significant utility. In this environment, the connectors of the present invention are disposed inside of the exterior wall 108 of an electronic device, such as a computer 101. Hence, the reference to "internal." The connectors of the present invention may also be used in an "external" application, as illustrated in FIG. 1B, wherein one of the connectors 110 is mounted to the circuit board 102, but extends partly through the exterior wall 108 of the device 101 so that it may be accessed by a user from the exterior of the device 101. The connector assembly 100 includes a pair of first and second interengaging connectors, described herein as respective receptacle (or socket) connectors 110 and plug connectors 104. One of these two connectors 110 is mounted to the printed circuit board 102 of the device 101, while the other connector 104 is typically terminated to a cable 105 that leads to a peripheral device.

FIG. 1 is a perspective view of the rear end of a receptacle, or socket connector, 200 of the type described in U.S. Patent No. 6,280,209, issued August 28, 2001, and owned by the assignee of the present invention. For purposes of clarity, the insulative material that normally forms the connector housing has been removed for purposes of clarity. This type of socket or receptacle connector typically includes a plurality of terminals 204 supported by an insulative housing (not shown), a portion of which is encompassed by a conductive metal shield 203. The terminals and leads from the metal shield are extended downwardly at the rear of the connector

to terminate in tail portions 205, which may be attached to conductive traces or pads 207 disposed on a printed circuit board 208.

In this type of arrangement, the terminals are arranged in two sets, and the bottom set of terminals which is supported on the bottom portion of the connector housing includes one or more channels of differential signal terminals, (meaning one wire carrying a positive voltage signal and the other wire carrying a negative voltage signal). The top portion of the connector housing includes and supports the ground terminals that are associated with the respective signal channels and other terminals such as power out and power return, as well as secondary and status terminals. In this arrangement, as shown in FIG. 1 and FIG. 2, the terminals 204 include contact portions 206a that are supported by the connector housing and which mate with contact portions of an opposing connector 104, tail portions 206c that are attached to the circuit board, either by way of surface mounting or by through hole mounting, and body portion 206b that interconnect the contact and tail portions together.

As see in FIG. 1, the body portions 206b of the terminals 204 of the top and bottom terminal sets are maintained in the same generally vertical plane in their extent down to the circuit board. Previously this had been done to maintain a desired dimensional relationship among each ground terminal and its two associated differential signal terminals. However, it becomes difficult at times to form these terminals in this manner and to maintain them in a single plane. Also, when the terminal body portions are maintained in a single plane as illustrated, any attempt at increasing the dimensions, i.e., width and surface area, of the ground terminals for each signal channel will result in an increase of the overall width **W** of the connector 100.

The present invention provides a solution to this problem. FIG. 3 illustrates a receptacle connector 300 constructed in accordance with the principles of the present invention. The connector finds its best utility in a circuit board application where it provides a means for connecting a cable to circuits 301 on a circuit board 302. The connector includes two distinct sets of terminals 305, 306 that are arranged in two distinct rows, typically top and bottom rows of the connector 300 which are supported on two distinct cantilevered leaf portions of the connector housing. The connector housing is preferably encompassed by a conductive metal shield 310 that extends around the contact portions in the mating region of the connector 300 to provide electrical shielding and a conductive surface that is electrically engageable with a shield of the opposing connector.

In the connector 300 of FIGS. 3-5, two signal channels are illustrated. Each signal channel includes a pair of signal terminals that are connected by way of their tail portions to differential signal circuit traces on the circuit board 302, and to terminals of the opposing connector 104 that are in turn terminated to differential signal wires of a cable 105. (FIG. 16B.) One signal channel "A" includes two signal terminals **SA1** and **SA2**, and also an associated ground terminal **GA**, while the other signal channel "B" includes two signal terminals **SB1** and **SB2** and their associated ground terminal **GB**. The signal terminals of this connector are preferably arranged as illustrated on the bottom leaf of the connector housing, while the ground terminals are arranged on the top leaf of the connector housing. Other terminals, such as power out and return terminals 310, 312 and a status or extra terminal 314 are also preferably arranged on the top leaf of the connector housing.

FIGS. 7-12 illustrate how the connectors of the invention are assembled. FIG. 7 illustrates a first, or top terminal module 320, that includes a body portion 321 and a leaf portion 322 that projects forwardly therefrom. The leaf portion 322 may include a plurality of channels or grooves 323 in which the ground, power and extra terminals are received. The grooves 323 are typically separated from each other by intervening walls 324 that are formed of the same material the body and leave portions are formed from, typically an insulative dielectric material. FIG. 9 illustrates a second, or bottom terminal module 330, which also includes a body portion 331 and a leaf portion 332 projecting therefrom that supports the second distinct set of terminals, namely the signal terminals **SA1-2** and **SB1-2** in a plane spaced apart from the plane in which the first set of terminals, i.e., the ground terminals, lie.

The second terminal module 330 also includes a series of grooves 333 which receive the second set of terminals, i.e., the signal terminals, and the leaf portion 332 includes a series of upstanding walls 334 that separate the grooves 333 from each other. The leaf portion 332 may also include an erect key portion 335 that separates the signal terminals of each channel and which provides a polarizing feature for the connector.

The two terminal modules 320, 330 may be assembled together in the fashion shown in FIG. 11. In this regard, the lower terminal module 330 may include a cavity 336 that receives a corresponding aligned projection 326 of the upper terminal module 320. Once assembled the two terminal modules are assembled together, they cooperatively form a connector subassembly 340, illustrated in FIG. 11. A conductive shield 310 may be applied to this subassembly 340 to extend around the terminal-supporting leaf portions 332, 322 of the two terminal modules 320,

330. In order to retain the shield 310 in place upon the subassembly 340, an insulative body portion 380 may be molded over portions of the two terminal modules 320, 330 and the shield 310 (such as the retainer tabs 311 thereof). This body portion 380 is shown in phantom in FIG. 6. Preferably, the body portion 380 is formed from a dielectric material that fills the intervening spaces between the ground and signal terminals and may, if desired, extend down to and over portions of the terminal tail portions 351, 361.

As mentioned previously, both sets of terminals have defined contact portions 350, 360 formed therein that are received by the respective terminal modules 320, 330, tail portions 351, 361 that are attached to circuit traces, either by way of surface mounting as shown in FIG. 3 or by through-hole mounting as illustrated in FIG. 16A, and terminal body portions 352, 362 that interconnect the terminal contact and tail portions together. The tail portions 351, 361 of the two sets of terminals are staggered, meaning that the signal terminal tail portions 361 are spaced apart from each other to define a series of intervening spaces S (FIG. 9) that receive the tail portions 351 of the top set of terminals so that all of the tail portions 351, 361 preferably line in the same attachment plane, illustrated in FIG. 11 as a horizontal plane and the attachment plane being a vertical plane in instances where the tails portions 351, 361 are through-hole mounting tails.

In an important aspect of the present invention, the signal terminals and ground terminals of the signal channels are maintained in a triangular relationship in both their contact and body portions and hence, each set of terminals that make up a signal channel is referred to as a "triad" or "triplet". This relationship is shown in FIG. 12 where the ground terminal **GB** is positioned at the top apex of an imaginary triangle **T**, and the signal terminals of this channel, **SB1** and **SB2** are positioned at the bottom two apexes of the triangle. This triangular relationship is important in that the dimensions between the signal and ground terminals may be varied, along with the size of the ground terminal of the signal channel in order to increase the capacitive and inductive coupling among the terminal group. An increase in capacitance will result in a lowering of the impedance of the signal channel. Likewise, manipulation of the terminals with respect to each other and their relative sizes will affect the inductance of the signal channel, which will also affect the impedance of the signal channel.

It has been found that increasing the size of the ground terminal, primarily the width thereof, increases the surface area of the ground terminal, which in turn increases the capacitance of the signal channel due to capacitive coupling that occurs between the two differential signal

terminals and the ground terminal. Prior to now, this increased width could not be maintained in the vertical body portion 352 of the ground terminals in connector of the prior art illustrated in FIGS. 1-2. With the connectors of the present invention, the body portions 352 of the ground terminals are offset, or moved back from, the body portions 362 of their associated signal terminals and preferably lie within their own plane. Thus, the width of the ground terminals **WG** may be increased to have a greater surface area than the widths **WS** of the signal terminals in the body portion area. This increased surface area increases the capacitance of the signal channel and results in a lowering of the overall impedance of the connector in that region.

Moreover, the out of plane spacing of the ground terminals with respect to the signal terminals, (i.e., the ground terminals being located in a vertical plane that is spaced apart from the plane in which the signal terminals are located) maintains a triangular relationship as illustrated by the imaginary triangle **T** in FIG. 5, with the signal terminals and ground terminal serving as apexes of the triangle. In this fashion, although the ground terminal **GB** may be considered as lying between the two signal terminals **SB1, SB2** when viewed from the rear of the connector as illustrated FIG. 4, the outer edges **OE** of the ground terminal **GB** preferably overlap the inner edges **IE** of its associated signal terminals. This size differential maintains the same material arrangement as found in the mating region, i.e., along the extent of the contact portions of the connector). This physical relationship results in a lowering of the impedance jump along line **M** in FIG. 18 from magnitude **H1** to that of **H11**.

The location of the ground terminals in their out of plane orientation also unexpectedly assists in the manufacturing of connectors of the invention. The two sets of terminals may be insert molded to their respective supporting terminal modules 320, 330 and then formed with greater reliability in the bending of the first set of terminals, i.e., the ground and power terminals, into their second plane. In order to assist in this forming process, as illustrated in FIG. 11, the first terminals may also have a support member 370 molded thereto which maintains the terminals in their spaced apart arrangement and which provides a contact point for a forming member to contact the first terminal set as an entire assembly and form it into its final location, offset from the first set of terminals. In order to further define the capacitance of the signal channel, the intervening spaces **"X"** that lie between adjoining terminals in the upper, or second set of terminals, may be filled with a dielectric material, typically the same material from which the first terminal module 320 is molded. The dielectric constant of this material may be chosen so as to impart a particular capacitance among the three terminals of each triplet, or triad. The

body portion 380 of the connector is molded over these terminals and its material will fill the vertical space between the ground and signal terminal body portions 352, 362. The dielectric material used to mold the body portion 3880 may be chosen for a desired dielectric constant in this area (best seen in FIG. 15 at "F".

Still further, the tail portions of the signal and ground terminals of the connector are maintained in a single plane, especially for surface mounting applications (it will be understood that in through-hole mounting applications, the terminal tail and body portions may be coincident or lie in a same plane). This plane is generally parallel to that of their respective contact blade portions 350, 360. Thus, the present invention provides a means to maintain the body and tail portions of signal channel terminals in two different planes while increasing the density of the connector as compared to connectors in which all of the terminal body portions are maintained in the same plane as illustrated in FIGS. 1-2.

By this structure, each pair of the differential signal terminals of the cable or circuit have an individual ground terminal associated with them that extends through the connector, thereby more closely resembling both the cable and its associated plug connector from an electrical performance aspect. Such a structure keeps the signal wires of the cable "seeing" the ground in the same manner throughout the length of the cable and in substantially the same manner through the receptacle connector interface and on to the circuit board. This connector interface is shown schematically in FIG 18. and may be considered as divided into four distinct Regions, I-IV, insofar as the impedance and electrical performance of the overall connection assembly or system is concerned. Region I refers to the cable 105 and its structure, while Region II refers to the termination area between the cable connector 104 and the cable 105 when the cable is terminated to the connector. Region III refers to the mating interface existent between the cable connector and the board connector 110 that includes the mating body portion of the connectors 104, 110. Region IV refers to the area that includes the termination between the board connector 110 and the circuit board 103. The lines "P," "N," and "M" of FIG. 17 have been superimposed upon FIG. 18 so that the two diagrams may be easily correlated.

The presence of an associated ground with the signal terminals importantly imparts capacitive coupling between the three terminals. This coupling is but one aspect that affects the ultimate overall impedance of the terminals of the connector. The resistance, terminal material and self-inductance are also components that affect the overall characteristic impedance of the connector insofar as the triplet of terminals is concerned. As discussed above, and with

reference to FIGS 4 & 5, the widths of the ground terminal body portions 352 is large enough so that it extends over, or at least partially overlaps portions of the signal terminal body portions 362. Preferably, a portion of the ground terminal always overlies or overlaps, a portion of at least one of the signal terminals associated with that particular signal channel. In other instances, the ground terminal may lie between or abut imaginary lines drawn up from the side edges of the signal terminals. The larger width of the ground terminal in the body portion thereof has a larger surface area compared to the surface areas of the corresponding signal terminal body portions and hence, the ground terminal body portion presents a larger and overlapping contact mating area in the region above the signal terminal body portions. Moreover, the increased width of the ground terminals in the body portions provides an additional benefit in that it makes them more robust which will facilitate their forming.

In the region of the ground and signal contact portions 350, 360 which lie in the mating interface of Region III of FIG. 18, the overall plate size of the ground terminals are increased relative to that of their associated signal terminals and thereby selectively diminishes the impedance of the connector. Likewise, in the second plane, occupied by both the spaced-apart signal and ground terminal body portions 352, 362, the spacing between the ground terminal and its signal terminals is increased, but the size of the ground terminal is increased so that the electrical effect, that of increased capacitance and reduced impedance of the connector is maintained when compared to a connector of the type illustrated in FIGS. 1 &2.

The effect of this tunability is explained in FIG. 17, in which a reduction in the overall impedance discontinuity occurring through the connector assembly is demonstrated. The impedance discontinuity that is expected to occur in the connectors of the present invention is shown by the dashed line 60 of FIG. 17. The solid line of FIG. 17 represents the typical impedance discontinuity that is experienced in the connector system of FIG. 3. By comparing the dashed and solid lines, the magnitudes of the peaks and valleys of this discontinuity, $\mathbf{H_{11}}$, $\mathbf{H_{22}}$ and $\mathbf{H_{33}}$ are greatly reduced. The present invention is believed to significantly reduce the overall discontinuity experienced in a conventional connector assembly. In one application, it is believed that the highest level of discontinuity will be about 135 ohms (at $\mathbf{H_{11}}$) while the lowest level of discontinuity will be about 85 ohms (at $\mathbf{H_{22}}$). The target baseline impedance of connectors of the invention will typically be about 110 ohms with a tolerance of about +/- 25 ohms. It is contemplated therefore that the connectors of the present invention will have a total discontinuity (the difference between $\mathbf{H_{11}}$ and $\mathbf{H_{22}}$)of about 50 ohms, which results in a decrease

from the conventional discontinuity of about 90 ohms referred to above of as much as almost 50%.

FIG. 19 illustrates another embodiment 400 of a terminal structure that may be utilized in connectors of the present invention. This embodiment 400 differs from the one previously described in that it uses an arrangement of asymmetrical signal terminals. In the connector of FIGS. 3-16, the signal terminal has a constant width for virtually its entire length in both the contact portion 360 and the body portions 362 thereof. It has been found that by making the signal terminals asymmetrical along their length, that the impedance of the connector may be further controlled. This asymmetry is shown in FIGS. 19 & 20, where it can be seen that the signal terminals 405 include contact portions 406, tail portions 407 and body, or transition portions 408 that interconnect the contact and tail portions 406 & 407 together. The signal terminal contact and body portions 406, 408 lie spaced apart from each other and spaced apart from the contact and body portion of their associated ground terminals 420. The asymmetry is provided by providing the signal terminals 405 with a first preselected width **Q** that extends for virtually the entire length of its contact portion 406. As shown best in FIG. 19, this width reduces, or tapers, or necks down to another width. In the body portion 408 thereof, the width is reduced down from the width **Q** to another, lesser value **G**, i.e., a second width, and this width may be further reduced down from **G** to an even lesser value **Y**, which is the typical width utilized for the tail portions 408 of the signal terminals.

FIG. 20 shows the asymmetry from the rear of the terminal structure and one can see that the first change in width (from **Q** to **G**) occurs in the contact portion area 406, and that the second change in width (from **G** to **Y**) occurs in the vertical body portion 408 of the terminals. As used herein, the terms "asymmetyrical" or asymmetry" are given their ordinary definitions, namely that if an imaginary center line were drawn through the terminals along their length, the portions of the terminal on opposite sides of the imaginary centerline would be different and not a mirror image of each other. These signal terminals differ from those of the other embodiment in that more material is present in the signal terminal body portion 408, which affects the impedance of the connector structure as between the signal terminals (in the differential impedance mode) as opposed to the impedance between the signal terminals and their ground terminal (in the common mode).

The use of asymmetrical signal terminals in the connectors of the invention provides beneficial and unexpected results. The differential signal terminals couple primarily with each

other along parts of the their body portions, primarily in the region that is disposed beneath the location where the ground terminal width decreases. This is indicated in FIG. 20. The ground terminals have a wide width along their contact portions and are elevated out of plane from the signal terminals and as such, diminished and controlled capacitive coupling occurs between the ground terminal contact portion and the two differential signal terminal contact portions. This is indicated in FIG. 20 in the top area labeled "Coupled". The width of the ground terminals is reduced in their body portions and up until this point, coupling primarily occurs between the ground terminals and their associated differential signal terminals.

However the width of the ground terminal body portions is reduced down to a second width in the body portions thereof and at a location, and in the embodiment illustrated in FIGS. 19 and 20, this location is above the contact portions of the signal terminals and above the location where they first reduce down in their width from **Q** to **G**, typically at the location where the contact portions of the terminal transition to the body portions. This larger width of the signal terminals along their body portion permits the ground terminal in the same area, i.e., along the body portions, to be reduced in width in the area closest to the differential signal terminal body portion. In this manner, coupling occurs between the ground and signal terminals in their contact portions and along their body portions until the ground terminal reduces in width. At this point, the signal terminals become "decoupled" from the ground terminal and primarily couple with each other. This is labeled in FIG. 20 "Decoupled". All three terminals eventually recouple in the tail portions of the ground and signal terminals where the ground terminal tail portion lies between the two associated signal terminal tail portions, and this region is labeled "Coupled" in FIG. 20.

By returning the ground terminals to the same attachment plane as the signal terminals, i.e., in the region of the tail portions, the ground terminal is "recoupled" to its two associated differential signal terminals in the tail portion region where the inductance typically increases. This adds coupling within the signal channel and reduces the impedance rise that would ordinarily be due to inductance.

While the preferred embodiments of the invention have been shown and described, it will be apparent to those skilled in the art that changes and modifications may be made therein without departing from the spirit of the invention, the scope of which is defined by the appended claims.

CLAIMS:

1. A connector assembly for effecting a connection between first and second electronic components, the components each including at least one differential pair of signal circuits and an associated ground circuit, the connector assembly comprising:

first and second connectors, said first and second connectors being engagable at mating portions thereof to effect said connection between said first and second electronic components,

said first and second connectors including respective first pairs of conductive differential signal terminals that engage each other when said first and second connectors are engaged together, and said first and second connectors including respective ground terminals that are associated with respective ones of said first pair of differential signal terminals, the respective ground terminals engaging each other when said first and second connectors are engaged together,

each of said ground and differential signal terminals of said first connector having contact portions, mounting portions, and body portions interconnecting said contact and mounting portions together, said ground and signal terminal contact portions being spaced apart from each other and extending in first and second distinct planes, said ground and signal terminal body portions being spaced apart from each other and extending in third and fourth distinct planes and intersecting said first and second planes such that said ground and differential signal terminal contact and body portions extend at angles to each other, said differential signal terminals maintaining an asymmetrical relationship with respect to each other throughout said signal terminal body portions.

2. The connector assembly of claim 1, wherein said differential signal terminal contact portions each have a first width, said differential signal terminal body portions each have a second width, and said differential signal terminal mounting portions each have a third width.

3. The connector assembly of claim 2, wherein said first width is great than said second width and said second width is great than said third width.

4. The connector assembly of claim 3, wherein said first width tapers to said second width in each of said contact portions and said second width tapers to said third width in each of said body portions.

5. The connector assembly of claim 1, wherein said ground terminal contact portion has a first width that is reduced to a second width in said ground terminal body portion at a level above said second plane.

6. The connector assembly of claim 1, wherein said first and second planes are parallel and said third and fourth planes are parallel.

7. The connector assembly of claim 1, wherein said ground terminal contact portion is contiguous.

8. An I/O connector assembly for effecting a connection between first and second electronic components, the components each including at least one differential pair of signal circuits and an associated ground circuit, the connector assembly comprising:

first and second connectors, said first and second connectors being engagable at mating portions thereof to effect said connection between said first and second electronic components,

said first and second connectors including respective first pairs of conductive differential terminals that engage each other when said first and second connectors are engaged together, and said first and second connectors including respective ground terminals that are associated with respective ones of said first pair of differential signal terminals, the respective ground terminals engaging each other when said first and second connectors are engaged together,

each of said ground and signal terminals of said first connector having contact portions, mounting portions, and body portions interconnecting said contact and mounting portions together, said signal terminal contact portions extending in a first plane and said signal terminal body portions extending in a second plane that intersects said first plane such that said differential signal terminal contact and body portions extend at angles to each other, said ground terminal contact portion extending in a third

plane and said ground terminal body portion extending in a fourth plane that intersects said third plane such that said ground terminal contact and body portions extend at an angle to each other, said first plane being spaced apart from said third plane and said second plane being spaced apart from said fourth plane, said ground terminal contact portion having a first width which is reduced to a second width in said ground terminal body portion at a level that is above said first plane.

9. The I/O connector assembly of claim 8, wherein said signal terminal body portions maintain an asymmetrical relationship with respect to each other.

10. The I/O connector assembly of claim 9, wherein said signal terminal contact portions each have a contact width, said signal terminal body portions each have a body width, and said signal terminal mounting portions each have a mounting width.

11 The I/O connector assembly of claim 10, wherein said contact width is great than said body width and said body width is great than said mounting width.

12. The I/O connector assembly of claim 11, wherein said contact width tapers to said body width in each of said contact portions and said body width tapers to said mounting width in each of said body portions.

13. The I/O connector assembly of claim 8, wherein said first and third planes are parallel and said second and fourth planes are parallel.

14. A connector for an electronic component, the electronic component including at least one differential pair of signal circuits and an associated ground circuit, the connector comprising:

at least one pair of conductive differential signal terminals, each of the differential signal terminals having contact portions, mounting portions, and body portions interconnecting said contact and mounting portions together, said differential signal terminal contact portions extending in a first plane and said differential signal

terminal body portions extending in a second plane that is substantially perpendicular to said first plane; and,

at least one ground terminal, said ground terminal being associated with said pair of differential signal terminals, said ground terminal having a contact portion, a mounting portion, and a body portion interconnecting said contact and mounting portions together, said ground terminal contact portion extending in a third plane and said ground terminal body portion extending in a fourth plane that is substantially perpendicular to said third plane,

said first plane being substantially parallel to and spaced apart from said third plane and said second plane being substantially parallel to and spaced apart from said fourth plane, said ground terminal contact portion having a first width which tapers down to a second width in said ground terminal body portion at a level that is above said first plane, said differential signal terminal contact portions each having a contact width that is greater than a body width of each of said signal terminal body portions, said body width being greater than a mounting width of each of said differential signal terminal mounting portions.

15. The connector of claim 14, wherein said differential signal terminal body portions maintain an asymmetrical relationship with respect to each other.

16. The connector of claim 14, wherein said contact width tapers to said body width in each of said differential signal terminal contact portions.

17. The connector of claim 14, wherein said body width tapers to said mounting width in each of said differential signal terminal body portions.

FIG. 1
(PRIOR ART)

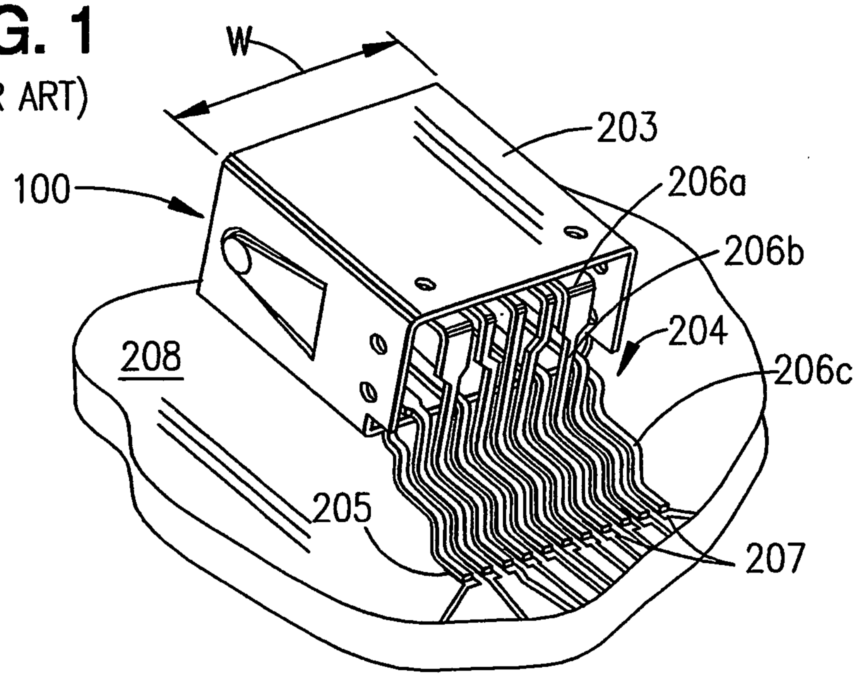


FIG. 2
(PRIOR ART)

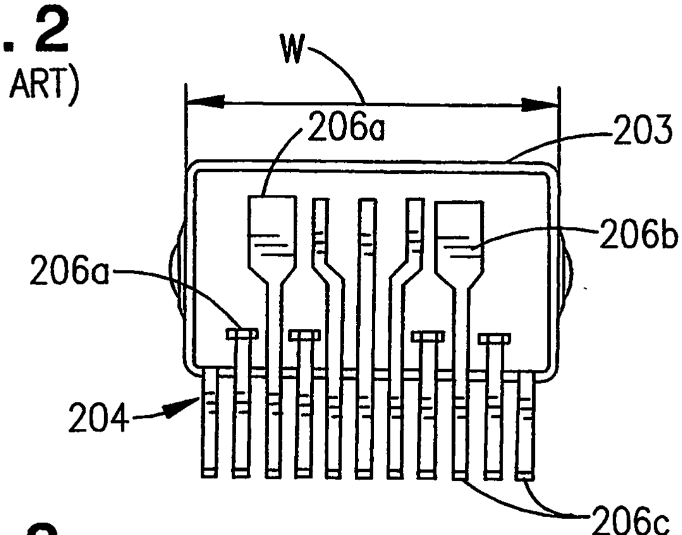


FIG. 3

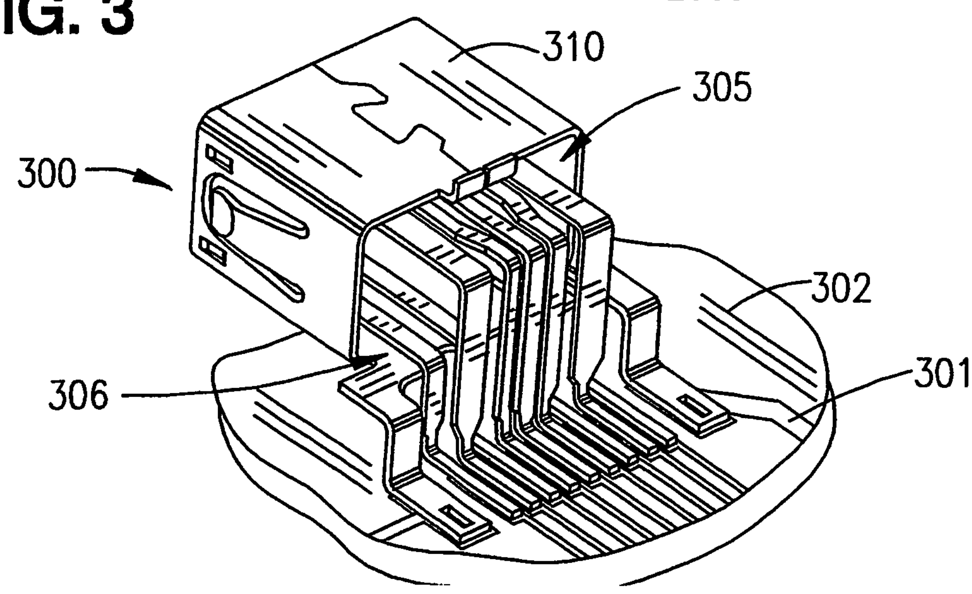


FIG. 4

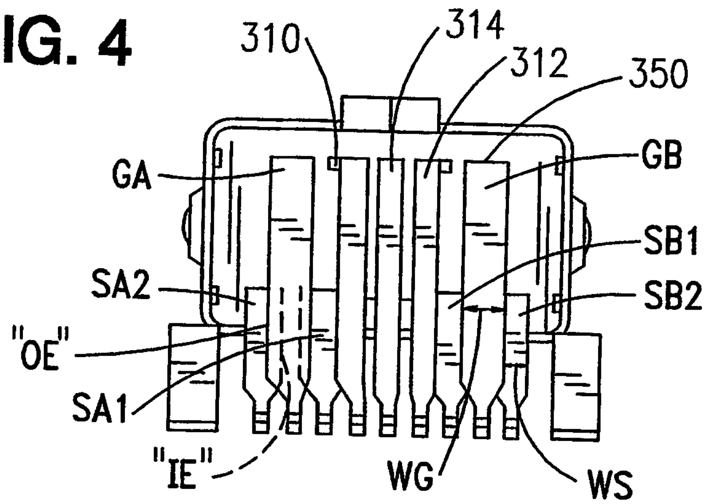


FIG. 5

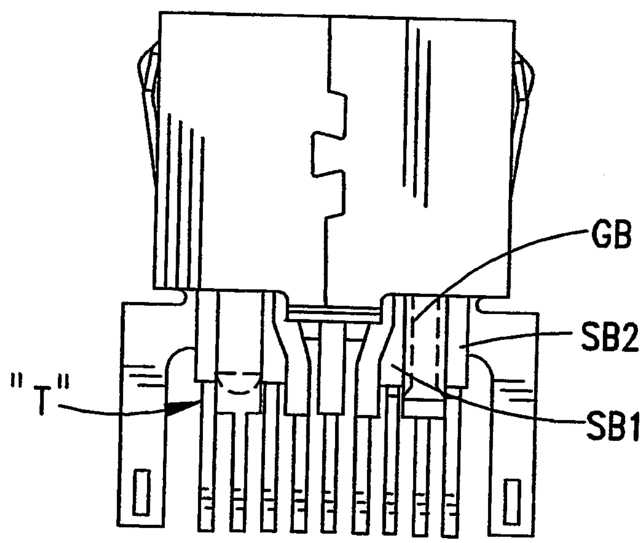


FIG. 7

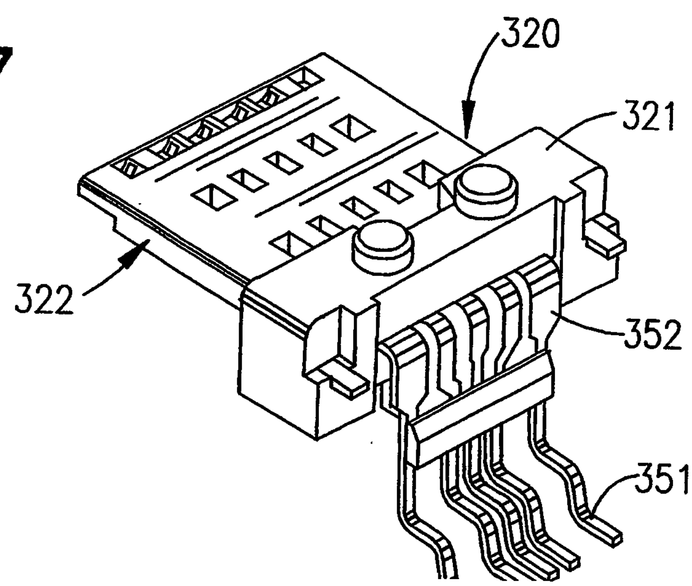


FIG. 6

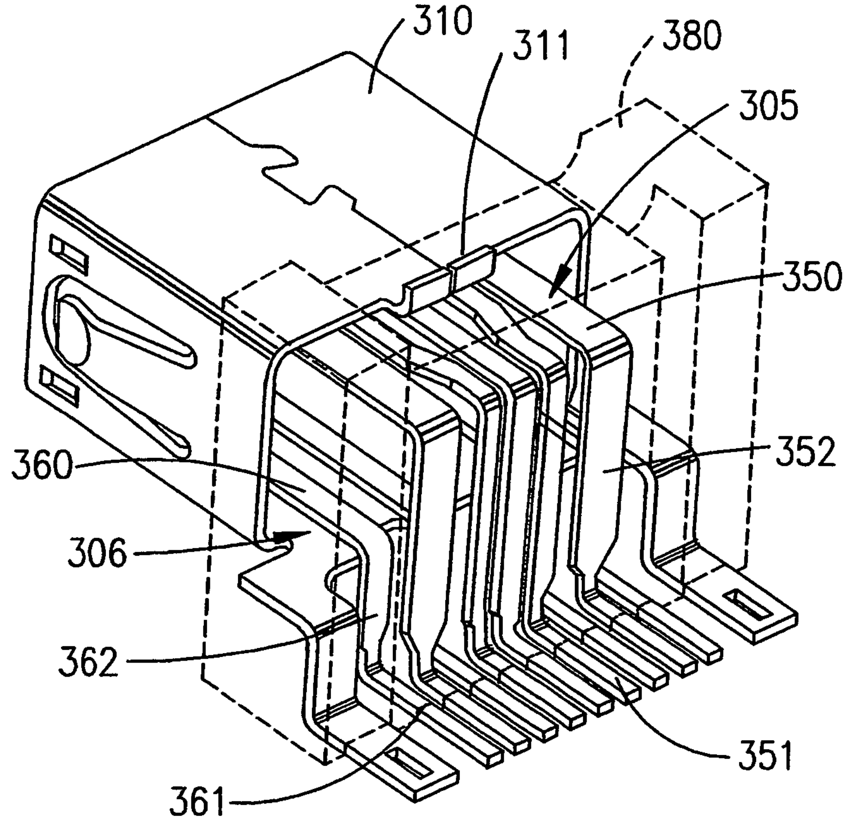


FIG. 8

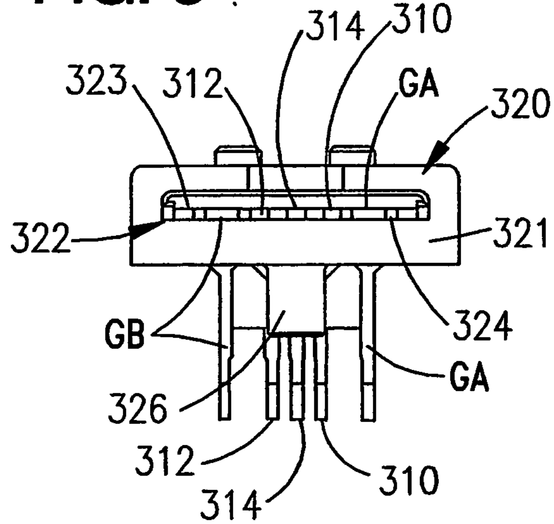


FIG. 9

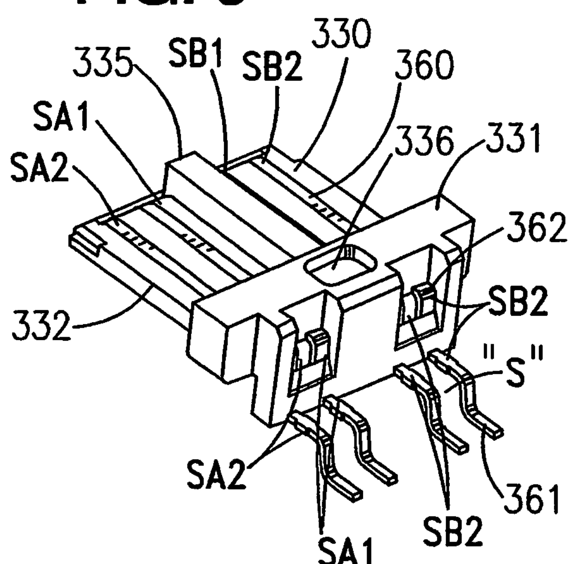


FIG. 10

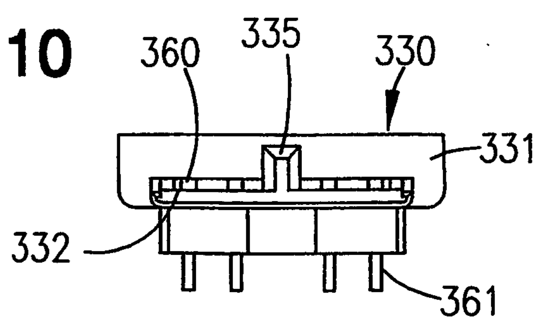


FIG. 11

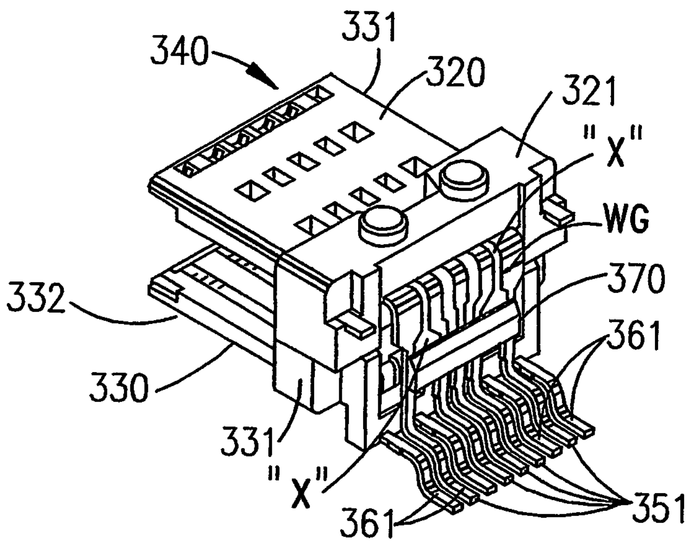


FIG. 12

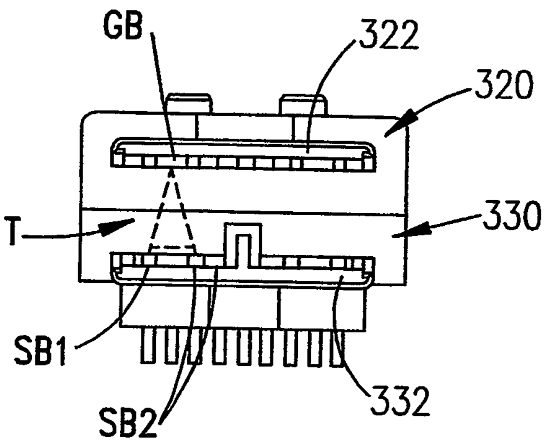


FIG. 13

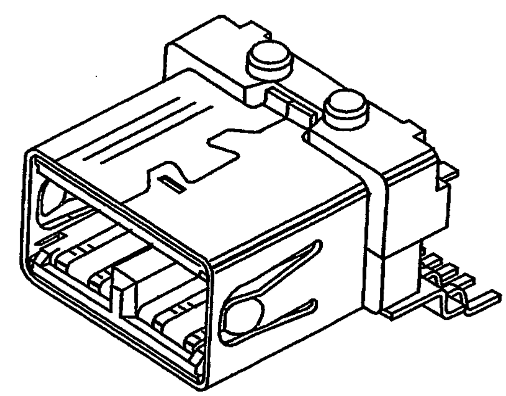


FIG. 15

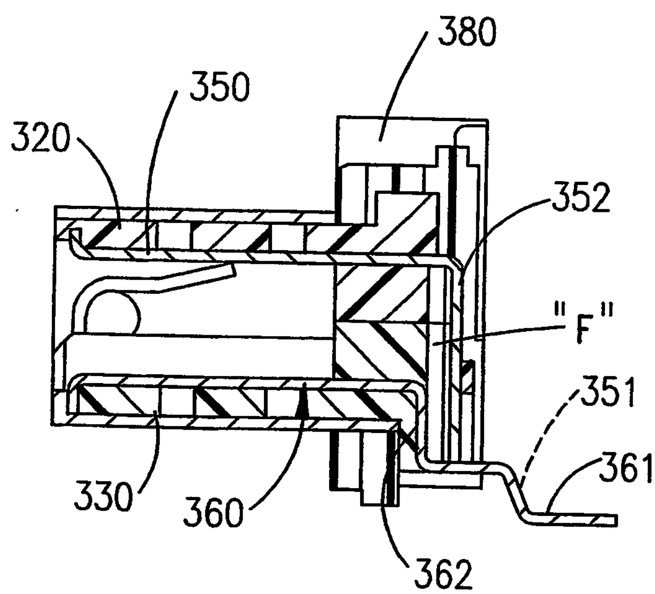


FIG. 14

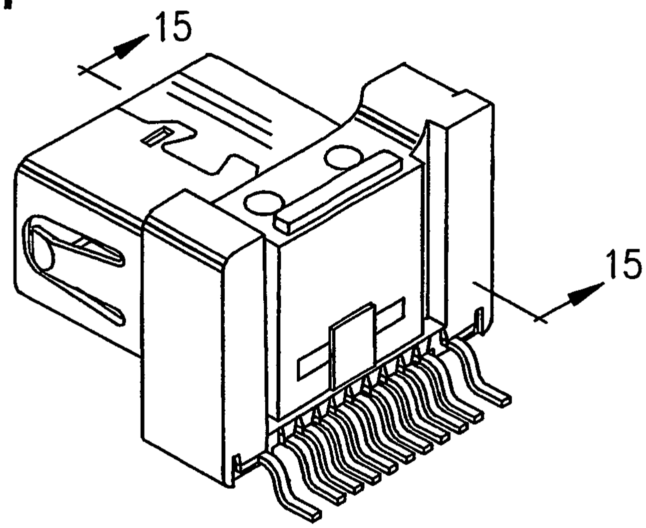


FIG. 16A

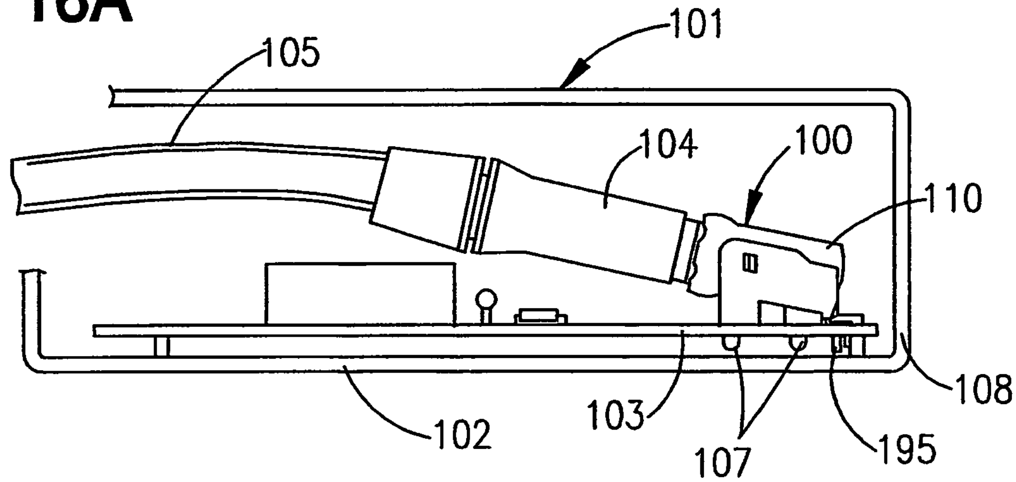


FIG. 16B

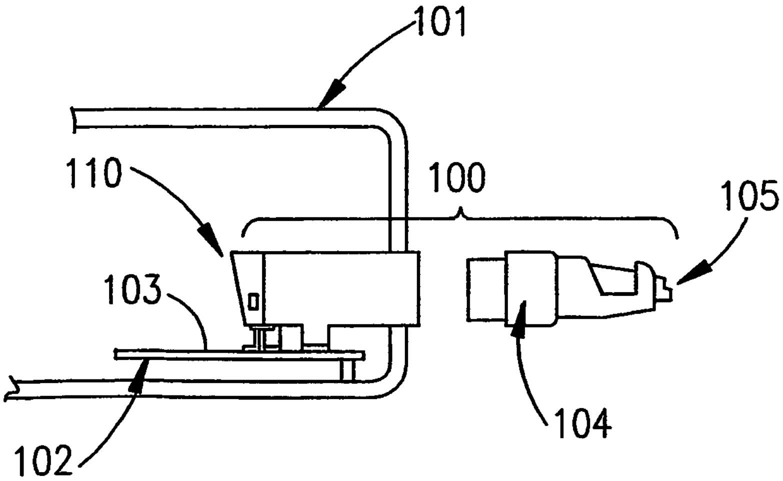
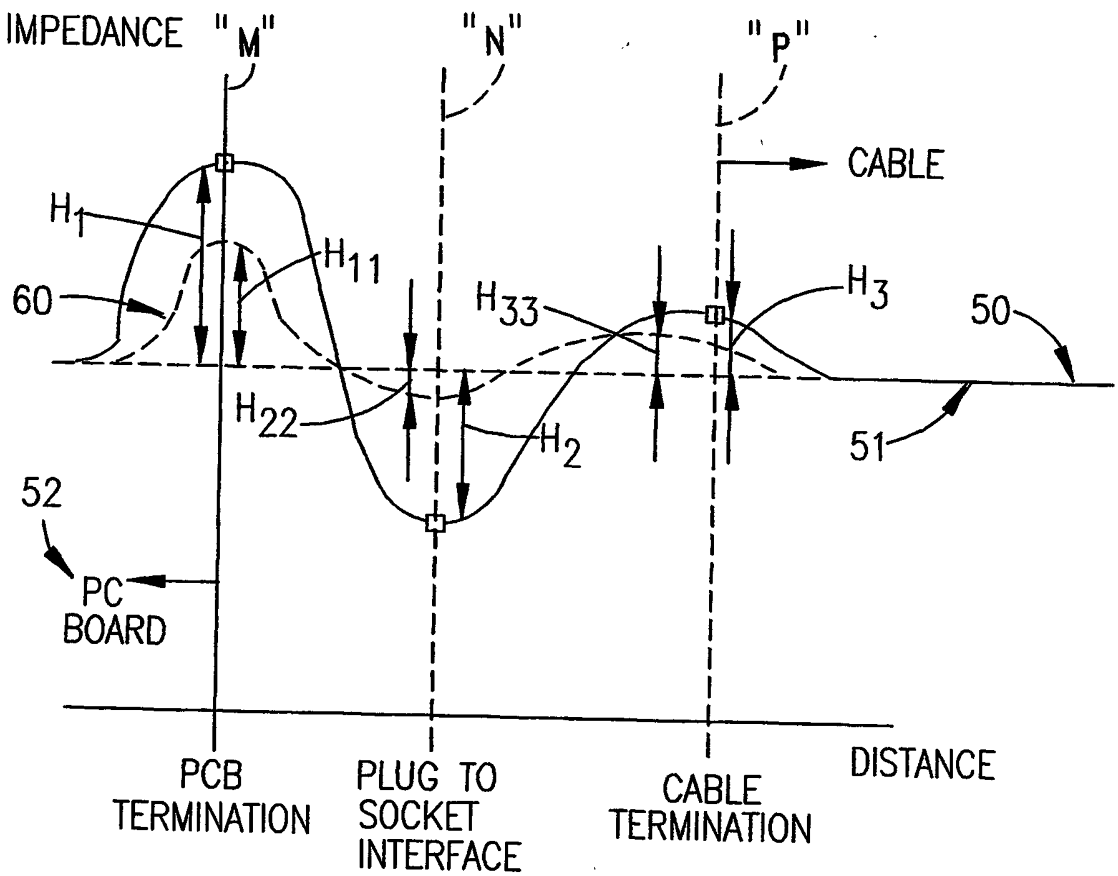


FIG. 17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H_{33}
H_3
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H_{22}
H_2
51
52
PC BOARD
PCB TERMINATION
PLUG TO SOCKET INTERFACE
CABLE TERMINATION
DISTANCE

FIG. 18

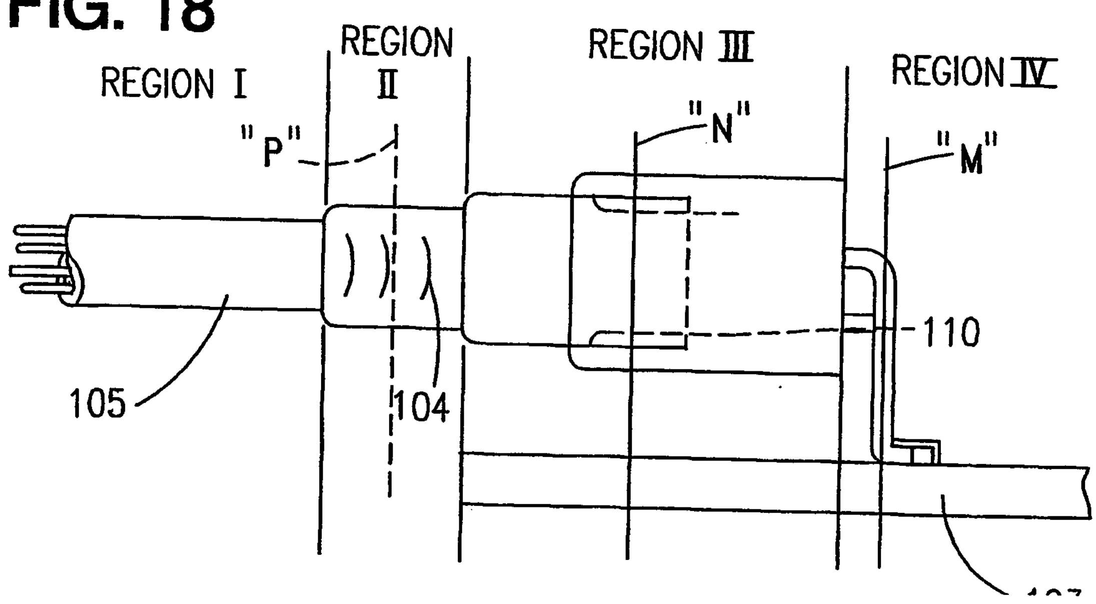
REGION I
REGION II
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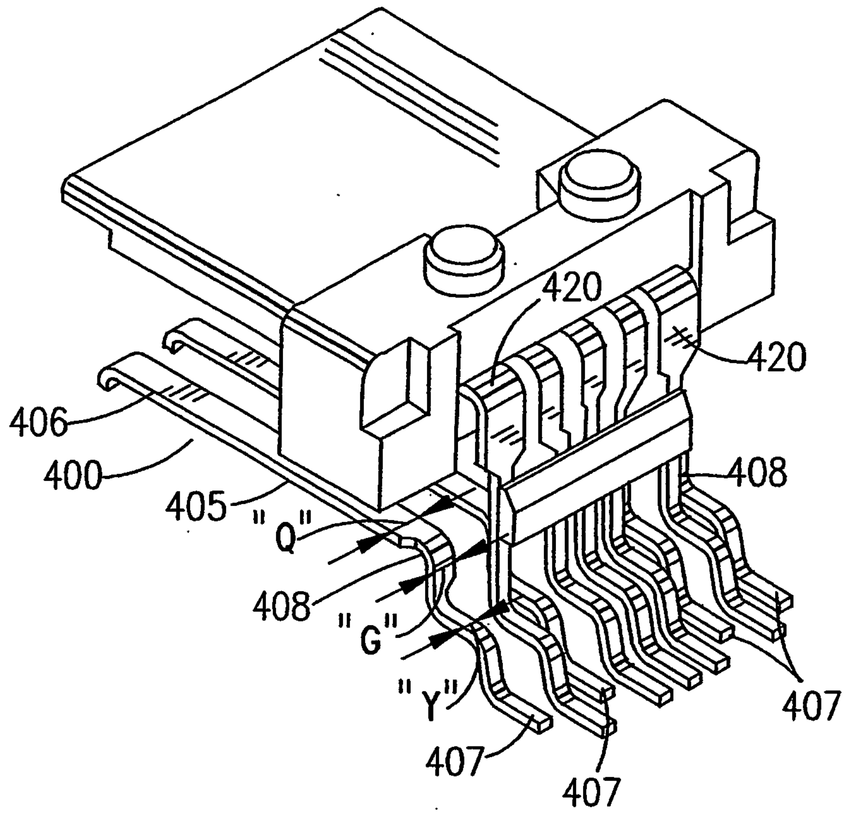
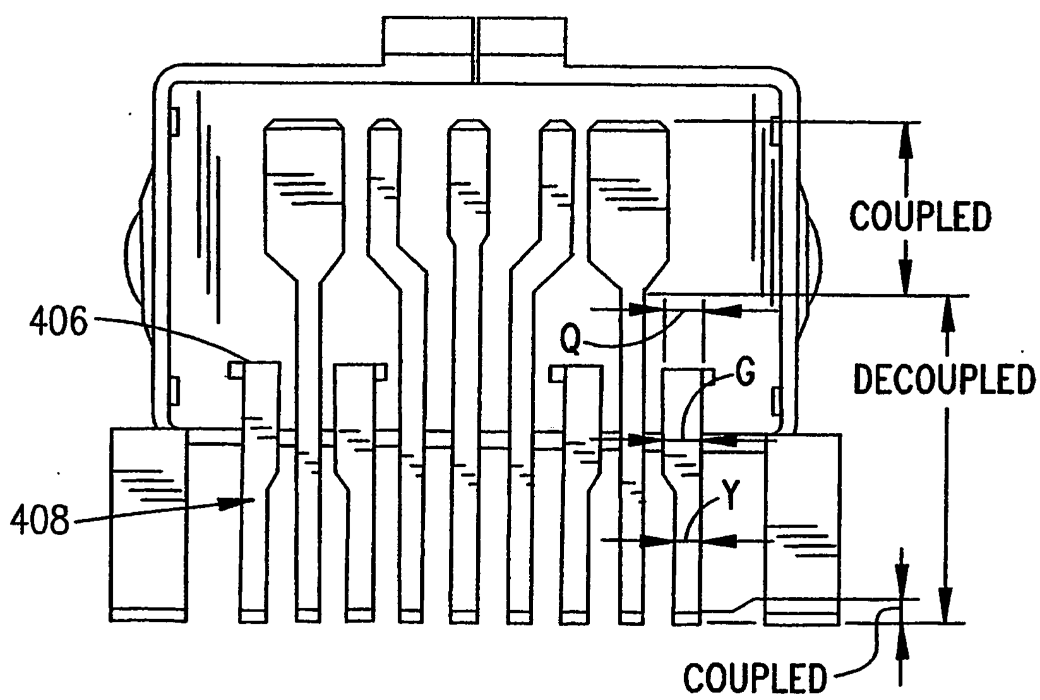
FIG. 19



420
420
406
400
405
"Q"
408
408
"G"
"Y"
407
407
407

FIG. 20



COUPLED
406
Q
DECOUPLED
G
408
Y
COUPLED

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/24761

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01R13/658

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 01 06602 A (MOLEX INC) 25 January 2001 (2001-01-25) page 8, line 32 -page 25, line 30	1-17
Y	US 6 059 581 A (WU KUN-TSAN) 9 May 2000 (2000-05-09) column 2, line 25 -column 4, line 39	1-17
A	US 6 099 351 A (WU KUN-TSAN) 8 August 2000 (2000-08-08)	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 September 2002	01/10/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk	

INTERN/)NAL SEARCH REPORT

Information on patent family members

In 'tional Application No
PCT/US 02/24761

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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